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(54) **SEMICONDUCTOR DEVICE AND
AUTOMOBILE**

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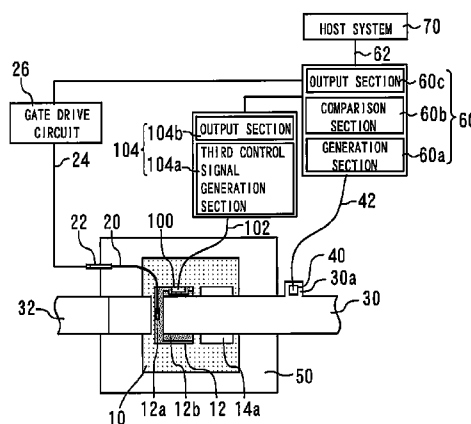
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(57) **ABSTRACT**

A semiconductor device includes a semiconductor element having a gate and controlled with a gate voltage, a gate drive circuit which controls the gate voltage, an electrode connected to the semiconductor element, a principal current in the semiconductor element flowing through the electrode, a temperature sensing part which senses the temperature of the electrode, a generation section which generates, on the basis of the temperature sensed by the temperature sensing part, a first control signal for giving a maximum amount of energization to the semiconductor element in such a range that the temperature of the electrode does not exceed a predetermined temperature, and a comparison section which compares the first control signal and a second control signal transmitted from the outside for the purpose of controlling the gate voltage, and selects a selective control signal which is one of the control signals with which the temperature of the electrode can be limited. The gate drive circuit controls the gate voltage according to the selective control signal.

8 Claims, 4 Drawing Sheets



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FIG. 1

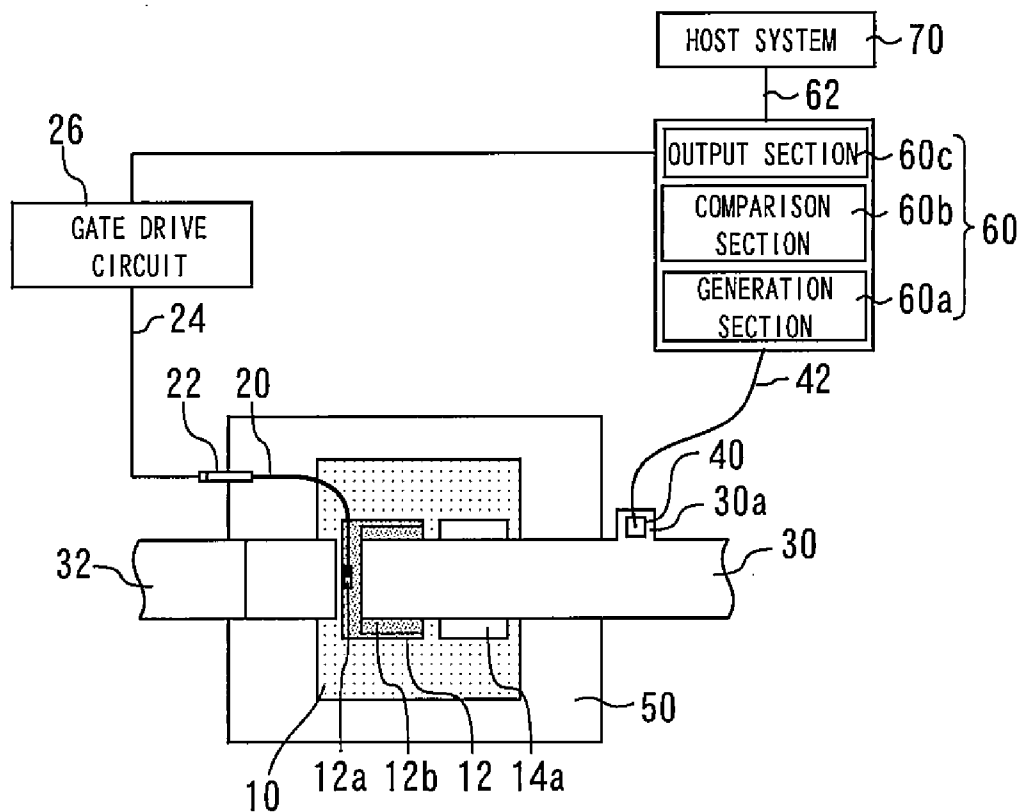


FIG. 2

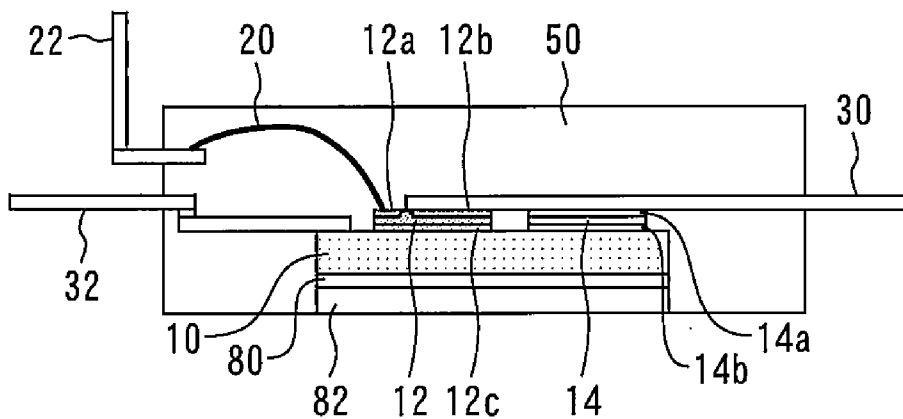


FIG. 3

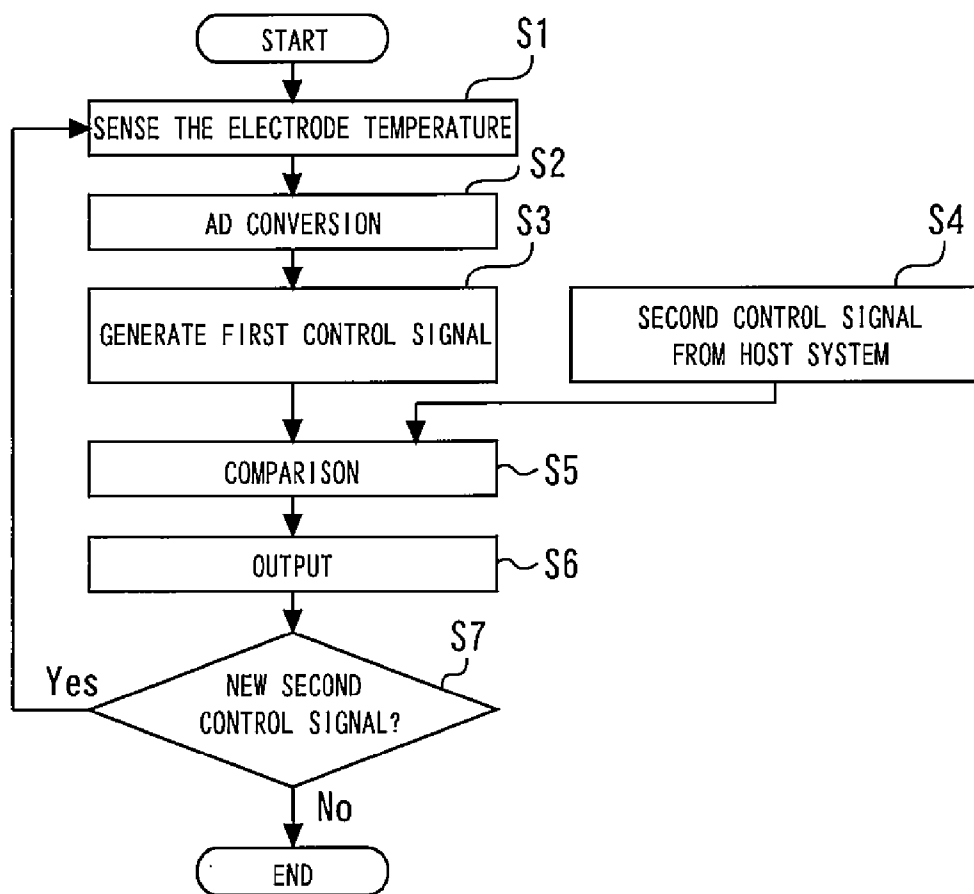


FIG. 4

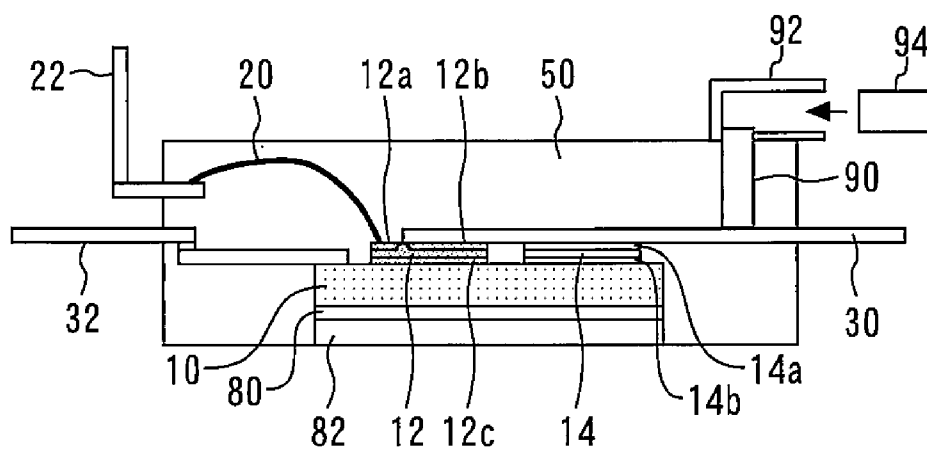


FIG. 5

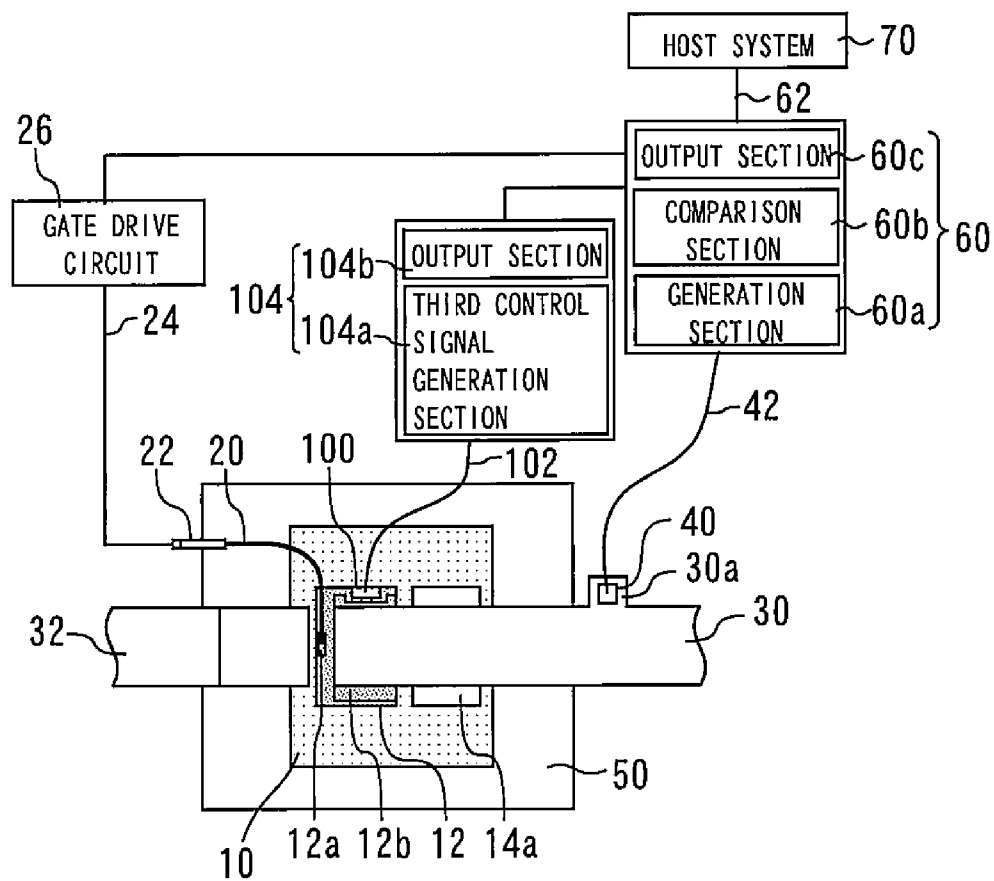


FIG. 6

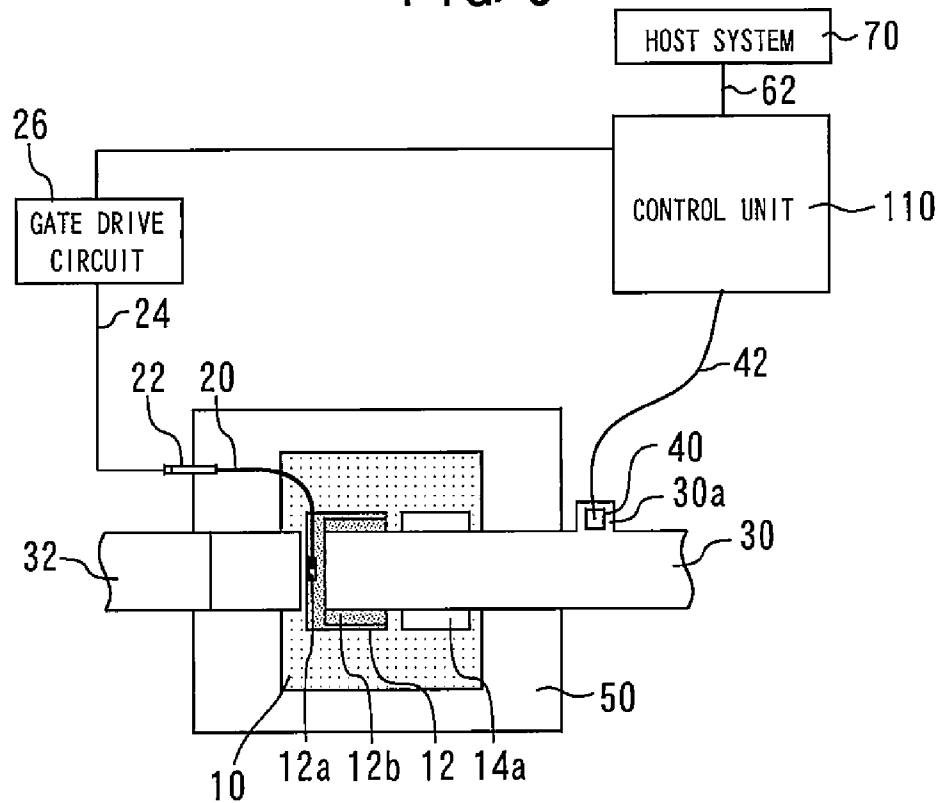
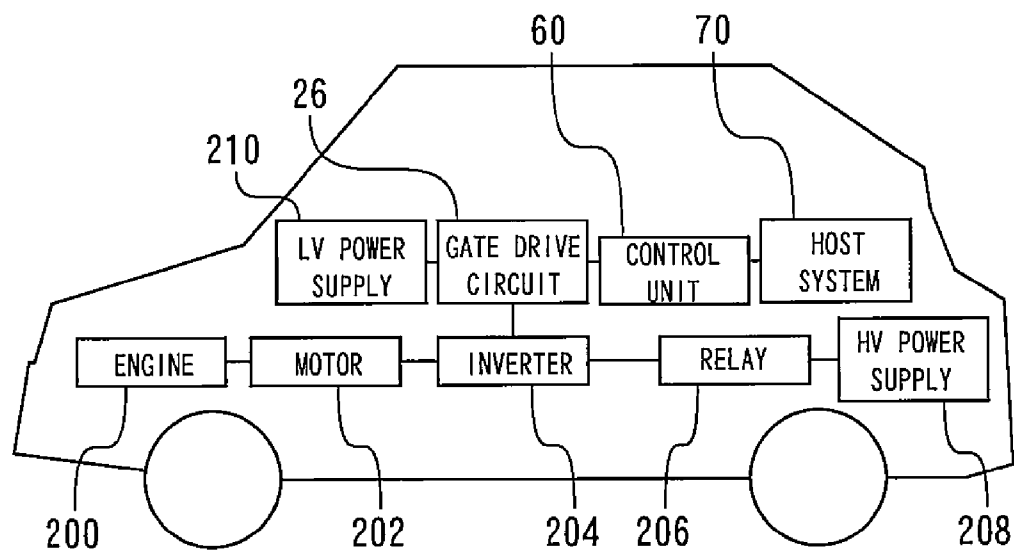


FIG. 7



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SEMICONDUCTOR DEVICE AND AUTOMOBILE

TECHNICAL FIELD

This present invention relates to a semiconductor device used for high-voltage large-current switching or the like and to an automobile provided with the semiconductor device.

BACKGROUND ART

Patent Literature 1 discloses a power semiconductor module having a semiconductor element, a collector electrode, an emitter electrode and a gate electrode junctioned to an insulating substrate with solder or the like. In this power semiconductor module, the temperatures of the semiconductor element and the component parts are measured with thermocouples, and degradation of the junction interface and the condition of cooling of a device are grasped from the measured changes in temperature. If a crack occurs and grows in the junction interface, the heat resistance increases and an increase in temperature occurs. Therefore, the progress of cracking can be determined by measuring the rate of increase in temperature.

PRIOR ART

Patent Literature

Patent Literature 1: Japanese Patent Laid-Open No. H07-014948

SUMMARY OF INVENTION

Technical Problem

In the arrangement disclosed in Patent Literature 1, there is a possibility of the temperatures of the semiconductor element and the electrode becoming high. Heat dissipation from the semiconductor element can easily be achieved by attaching a heat sink or the like to the semiconductor element. However, heat dissipation from the electrode to which no heat sink is attached is not easy to achieve. Also, a great part of the electrode is covered with the resin in the semiconductor device. Therefore, heat accumulates easily in and around the electrode. There is, therefore, a problem that keeping the temperature of the electrode equal to or lower than a predetermined specified value requires increasing the size of the electrode.

The present invention has been achieved to solve the above-described problem, and an object of the present invention is to provide a semiconductor device in which the size of an electrode can be reduced while the temperature of the electrode is kept equal to or lower than a specified value, and an automobile including the semiconductor device.

Means for Solving the Problems

A semiconductor device according to the present invention includes a semiconductor element having a gate and controlled with a gate voltage, a gate drive circuit which controls the gate voltage, an electrode connected to the semiconductor element, a principal current in the semiconductor element flowing through the electrode, a temperature sensing part which senses the temperature of the electrode, a generation section which generates, on the basis of the temperature sensed by the temperature sensing part, a first

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control signal for giving a maximum amount of energization to the semiconductor element in such a range that the temperature of the electrode does not exceed a predetermined temperature, and a comparison section which compares the first control signal and a second control signal transmitted from the outside for the purpose of controlling the gate voltage, and selects a selective control signal which is one of the control signals with which the temperature of the electrode can be limited, wherein the gate drive circuit controls the gate voltage according to the selective control signal.

Other features of the present invention will be made clear by the following description.

Advantageous Effects of Invention

According to the present invention, the control signal is changed on the basis of the detected temperature of the electrode temperature so that the electrode temperature does not exceed a specified value. Therefore, the size of the electrode can be reduced while the temperature of the electrode is kept equal to or lower than the specified value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a semiconductor device according to Embodiment 1 of the present invention.

FIG. 2 is a sectional view showing portions inside the resin.

FIG. 3 is a flowchart showing the operation of the semiconductor device according to Embodiment 1 of the present invention.

FIG. 4 is a sectional view showing an example of modification with respect to the position at which the temperature sensing part is mounted.

FIG. 5 is a diagram of the semiconductor device according to Embodiment 2 of the present invention.

FIG. 6 is a diagram of the semiconductor device according to Embodiment 3 of the present invention.

FIG. 7 is a diagram showing the automobile according to Embodiment 4 of the present invention.

DESCRIPTION OF EMBODIMENTS

Semiconductor devices according to embodiments of the present invention will be described with reference to the drawings. Components identical or corresponding to each other are indicated by the same reference characters, and repetition of description is avoided in some cases.

Embodiment 1

FIG. 1 is a diagram of a semiconductor device according to Embodiment 1 of the present invention. This semiconductor device is provided with a substrate 10. The substrate 10 is formed of a heat spreader for example. A semiconductor element 12 is fixed on the substrate 10 with solder for example. The semiconductor element 12 is formed of an IGBT having a gate 12a and an emitter 12b on its surface. A diode 14 which functions as a reflux diode is fixed by the side of the semiconductor element 12 on the substrate 10 with solder for example. The diode 14 has a surface electrode 14a.

A gate electrode 22 is connected to the gate 12a through a wire 20. The gate electrode 22 is connected to a gate drive circuit 26 through a wire 24. The gate drive circuit 26 is a

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component for controlling a gate voltage on the gate **12a**. The semiconductor element **12** is controlled through this gate voltage.

An electrode **30** is fixed on the emitter **12b** and the surface electrode **14a** with solder for example. A principal current in the semiconductor element **12** flows through the electrode **30**. The electrode **30** has a branch portion **30a** branching off from a principal current path. A temperature sensing part **40** is attached to the branch portion **30a**. The temperature sensing part **40** is formed of a thermocouple for sensing the temperature of the electrode **30**. An electrode **32** is fixed on the substrate **10**. The electrode **32** is electrically connected to a collector on the back surface of the semiconductor element **12** through the substrate **10**.

The semiconductor element **12**, the diode **14**, the gate electrode **22** and the electrodes **30** and **32** are covered with a resin **50**, with a portion of the gate electrode **22** and portions of the electrodes **30** and **32** exposed to the outside. The electrodes **30** and **32** are extended out of the resin **50** for connection to external bus bars. The above-described branch portion **30a** and the temperature sensing part **40** are also exposed out of the resin **50**.

A control unit **60** is connected to the temperature sensing part **40** through a wire **42**. The control unit **60** is provided with a generation section **60a**, a comparison section **60b** and an output section **60c**. The generation section **60a** is a section which generates, on the basis of the temperature sensed by the temperature sensing part **40**, a first control signal for giving a maximum amount of energization to the semiconductor element **12** in such a range that the temperature of the electrode **30** does not exceed a predetermined temperature (specified value). The control signal determines the time period for which the semiconductor element **12** is energized. For example, the control signal is a signal relating to the duty ratio and switching achieved with an arm.

A host system **70** is connected to the control unit **60** through a wire **62**. The host system **70** is a unit which transmits to the control unit **60** a second control signal for controlling the gate voltage. The host system **70** is not necessarily included in the semiconductor device according to Embodiment 1 of the present invention. That is, if the control unit **60** can receive the signal from the "outside", the host system **70** is not indispensable. The same can be said with respect to embodiments described below. The comparison section **60b** is a section which compares the first control signal and the second control signal and selects one of the control signals with which the temperature of the electrode **32** can be limited. The control signal selected by the comparison section **60b** is called "selective control signal". The output section **60c** is a section which transmits the selective control signal to the gate drive circuit **26**.

FIG. 2 is a sectional view showing portions inside the resin **50**. The semiconductor element **12** has a collector **12c** on its back surface. The diode **14** has a back electrode **14b** on its back surface. The collector **12c** and the back electrode **14b** are fixed on the front surface of the substrate **10** with solder for example. An insulating sheet **80** is applied to the back surface of the substrate **10**. Copper foil **82** is fixed on the back surface of the substrate **10**, with the insulating sheet **80** interposed therebetween. It is preferable that a heat sink be fixed to the copper foil **82**, for example, by soldering, ultrasonic joining, brazing, welding or bonding with an adhesive.

The operation of the semiconductor device according to Embodiment 1 of the present invention will be described. FIG. 3 is a flowchart showing the operation of the semiconductor device according to Embodiment 1 of the present

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invention. First, the temperature of the electrode **30** is sensed by the temperature sensing part **40** (step S1). Since the temperature sensing part **40** is a thermocouple, thermoelectromotive force (voltage signal) is transmitted to the control unit **60** through the wire **42**.

Next, the sensed temperature (thermoelectromotive force) is converted into a digital value by the generation section **60a** (step S2). Subsequently, the generation section **60a** generates the first control signal on the basis of digital value into which the thermoelectromotive force has been converted (step S3). The generation section **60a** uses, for example, data on the shape of the electrode **30** stored in the generation section **60a** (hereinafter referred to as a shape model) for the calculation of the first control signal. Parameters included in the shape model are, for example, the thickness of the substrate **10** and the thickness, width and length of the electrode **30**. The first control signal is a signal for giving the maximum amount of energization to the semiconductor element **12** in such a range that the temperature of the electrode **30** does not exceed a specified value, as described above.

Subsequently, the comparison section **60b** compares the first control signal and the second control signal and selects one of these control signals (selective control signal) with which the temperature of the electrode **32** can be limited (step S5). Subsequently, the output section **60c** transmits this selective control signal to the gate drive circuit **26** (step S6). The gate drive circuit **26** then controls the gate voltage according to the selective control signal.

Subsequently, if a new second control signal has been issued, the above-described process steps are again executed. If no new control signal has been issued, the process ends (step S7). Such a sequence of operations is executed at least each time the second control signal sent from the host system **70** to the control unit **60**. A more preferable operation is to continuously update the first control signal at all times by continuously sensing the temperature of the electrode **30** with the temperature sensing part **40** and to compare the latest first control signal and the second control signal.

In the semiconductor device according to Embodiment 1 of the present invention, the second control signal issued from the host system **70** is not adopted when it is a signal to increase the temperature of the electrode **30** above the specified value, and the semiconductor element **12** can be controlled with the first control signal in this case. Selecting not the second control signal but the first control signal is substantially equivalent to reducing the amount of energization with the second control signal. The temperature of the electrode **30** can thus be kept equal to or lower than the specified value. Since use of the small electrode **30** is presupposed in the present invention, setting the specified value with respect to the small electrode **30** enables preventing the temperature of the electrode from exceeding the specified value. Thus, the electrode can be reduced in size while the temperature of the electrode is kept equal to or lower than the specified value.

It is preferable that with the first control signal generated by the generation section **60a**, the maximum amount of energization be given to the semiconductor element in such a range that the specified value is not exceeded in order that the desired control with the host system **70** should be ensured as extensively as possible. Therefore, the first control signal should be generated with accuracy. In the semiconductor device according to Embodiment 1 of the present invention, the accuracy with which the temperature of the electrode **30** is predicted is high since the first control signal

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is generated by using the shape model stored in the generation section **60a**. The first control signal can therefore be generated with accuracy.

In Embodiment 1 of the present invention, the first control signal is generated by using a shape model. However, the present invention is not limited to this. For example, the generation section **60a** may generate the first control signal by using map data in which the first control signal corresponding to the electrode temperature is stored. In such a case, the first control signal can be immediately generated from the electrode temperature by using map data without needing to calculate it, and the processing speed can therefore be increased.

FIG. 4 is a sectional view showing an example of modification with respect to the position at which the temperature sensing part is mounted. The semiconductor device in this case is provided with a metal part **90** connected to the electrode **30** in the resin **50** and having its portion exposed out of the resin **50**. The semiconductor device is also provided with a socket **92** having as a point of contact the portion of the metal part **90** exposed out of the resin **50**. A temperature sensing part **94** has such a shape as to be capable of being inserted in the socket **92**. This arrangement ensures that sensing of the temperature of the electrode **30** is enabled by only inserting the temperature sensing part **94** in the socket **92**. The socket **92** may be removed and the temperature sensing part may be fixed on the metal part **90**.

In the semiconductor device according to Embodiment 1 of the present invention, the temperature of the electrode through which the principal current in the semiconductor element **12** flows is measured. Therefore, the temperature sensing part may be attached to any portion of the electrode through which the principal current flows, which portion is not limited to the metal part **90** in the socket **92** or branch portion **30**.

The temperature sensing part **40** is not limited to the thermocouple. Any other sensing part may suffice if it is capable of sensing temperature. For example, the temperature sensing part **40** may be formed of a thermal diode. The semiconductor element **12** is not particularly limited to the IGBT. Any other semiconductor element may suffice if it is on/off controlled through a gate voltage. For example, a power MOSFET may be used as semiconductor element **12**. Each of the above-described modifications can be applied to embodiments described below.

Embodiment 2

A semiconductor device according to Embodiment 2 of the present invention corresponds in a number of respects to the semiconductor device according to Embodiment 1 and will therefore be described mainly with respect to points of difference from the semiconductor device according to Embodiment 1. FIG. 5 is a diagram of the semiconductor device according to Embodiment 2 of the present invention. In this semiconductor device, the temperature of the semiconductor element **12** is detected as well as that of the electrode **30**.

An element temperature sensing part **100** is attached to a surface of the semiconductor element **12**. The element temperature sensing part **100** is formed, for example, of a thermocouple. An element temperature monitoring unit **104** is connected to the element temperature sensing part **100** through a wire **102**. The element temperature monitoring unit **104** is provided with a third control signal generation section **104a** and an output section **104b**. The third control signal generation section **104a** is a section which generates,

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on the basis of the temperature sensed by the element temperature sensing part **100**, a third control signal for giving a maximum amount of energization to the semiconductor element **12** in such a range that the temperature of the semiconductor element **12** does not exceed a predetermined temperature (element specified value). The output section **104b** is a section which transmits the third control signal to the control unit **60**.

The operation of the semiconductor device according to Embodiment 2 of the present invention will be described. The comparison section **60b** compares the first control signal, the second control signal and the third control signal, and selects as a selective control signal one of these control signals with which the temperature of the electrode **32** can be limited most strongly. This selective control signal is also a control signal with which the temperature of the semiconductor element **12** can be limited most strongly.

The semiconductor device according to Embodiment 2 of the present invention is capable of controlling the semiconductor element **12** with the selective control signal so that the temperature of the semiconductor element **12** does not exceed the element specified value and the temperature of the electrode **30** does not exceed the specified value. Thus, the reliability of the semiconductor element **12** is ensured while the same advantages as those of Embodiment 1 are obtained.

Embodiment 3

A semiconductor device according to Embodiment 3 of the present invention corresponds in a number of respects to the semiconductor device according to Embodiment 1 and will therefore be described mainly with respect to points of difference from the semiconductor device according to Embodiment 1. FIG. 6 is a diagram of the semiconductor device according to Embodiment 3 of the present invention. The difference of this semiconductor from the corresponding one in Embodiment 1 resides in a control unit **110**.

The control unit **110** changes, on the basis of the temperature sensed by the temperature sensing part **40**, the content of the control signal transmitted from the host system **70** for control of the gate voltage so that the temperature of the electrode **30** does not exceed a predetermined temperature (specified value). This changing is performed when the control signal transmitted from the host system **70** to the control unit **110** is such as to increase the temperature of the electrode above the specified value. More specifically, a change to be made is, for example, a decrease in energization current to the semiconductor element **12** or a reduction in the time period during which the semiconductor element **12** is energized (signal width). The amount of this reduction is increased if the temperature sensed by the temperature sensing part **40** is higher. The gate drive circuit **26** controls the gate voltage according to the control signal changed as required by the control unit **110**.

The semiconductor device according to Embodiment 3 of the present invention uses as a basis for control the control signal transmitted from the host system **70** and makes a change in this control signal, thereby obtaining the same advantages as those of the semiconductor device in Embodiment 1 while simplifying the configuration of the control unit **110**.

Embodiment 4

Embodiment 4 of the present invention relates to an automobile. The automobile according to Embodiment 4 of

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the present invention includes the semiconductor device according to Embodiment 1. FIG. 7 is a diagram showing the automobile according to Embodiment 4 of the present invention. This automobile is a hybrid vehicle which travels by using both or one of an engine **200** and a motor **202**. The motor **202** is controlled with an inverter **204**. The inverter **204** includes the semiconductor device described with reference to FIG. 1. More specifically, a three-phase alternating-current inverter is formed by arranging six semiconductor elements **12**. The motor **202** is controlled with principal currents in the semiconductor elements included in the inverter **204**.

A high voltage to the inverter **204** is supplied from a high-voltage power supply **208** through a relay **206**, while a low voltage to a gate drive circuit **26** is supplied from a low-voltage power supply **210**.

Pattern of energization current of vehicle power modules include a pulse energization mode used for normal operation and a DC energization mode used at the time of motor locking. Semiconductor elements such as IGBTs are ordinarily designed so that generation of heat from the element is limited by a temperature sensing function. It is, therefore, easy to optimize the size of such semiconductor elements. On the other hand, if electrodes (electrodes **30** and **32** in FIG. 1) are designed on the basis of the DC current in the energization mode, increases in size of the electrodes cannot be avoided.

In the automobile according to Embodiment 4 of the present invention, the electrode temperature can be kept equal to or lower than the specified value by selecting the first control signal with the comparison section **60b** in the control unit **60** when a large current flows, for example, in the DC energization mode, and, therefore, the electrodes can be reduced in size. Accordingly, the automobile can be reduced in size. The semiconductor device according to Embodiment 2 or 3 may be adopted for the automobile according to Embodiment 4 of the present invention.

DESCRIPTION OF SYMBOLS

10 substrate, **12** semiconductor element, **12a** gate, **12b** emitter, **12c** collector, **14** diode, **14a** surface electrode, **14b** back electrode, **20,24,42,62** wire, **22** gate electrode, **26** gate drive circuit, **30, 32** electrode, **30a** branch portion, **30** temperature sensing part, **50** resin, **60** control unit, **60a** generation section, **60b** comparison section, **60c** output section, **70** host system, **80** insulating sheet, **82** copper foil, **90** metal part, **92** socket, **94** temperature sensing part, **100** element temperature sensing part, **104** element temperature monitoring unit, **104a** third control signal generation section, **104b** output section, **110** control unit, **200** engine, **202** motor, **204** inverter

The invention claimed is:

1. A semiconductor device comprising:

a semiconductor element having a gate and controlled with a gate voltage;
a gate drive circuit which controls the gate voltage;
an electrode connected to the semiconductor element, a principal current in the semiconductor element flowing through the electrode;
a temperature sensing part, in physical contact with the electrode, which senses the temperature of the electrode;
a generation section which generates, on the basis of the temperature sensed by the temperature sensing part, a first control signal for giving a maximum amount of energization to the semiconductor element in such a

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range that the temperature of the electrode does not exceed a predetermined temperature; and

a comparison section which compares the first control signal and a second control signal transmitted from the outside for the purpose of controlling the gate voltage, and selects a selective control signal which is one of the control signals with which the temperature of the electrode can be limited,

wherein the gate drive circuit controls the gate voltage according to the selective control signal.

2. The semiconductor device according to claim 1, wherein the generation section generates the first control signal by using a shape model of the electrode.

3. The semiconductor device according to claim 1, wherein the generation section generates the first control signal by using map data in which the first control signal corresponding to the temperature of the electrode is stored.

4. The semiconductor device according to claim 1, further comprising:

an element temperature sensing part attached to the semiconductor element; and

a third control signal generation section which generates, on the basis of the temperature sensed by the element temperature sensing part, a third control signal for giving a maximum amount of energization to the semiconductor element in such a range that the temperature of the semiconductor element does not exceed a predetermined temperature,

wherein the comparison section compares the first control signal, the second control signal and the third control signal.

5. The semiconductor device according to claim 1, wherein the electrode has a branch portion branching off from a main current path, and the temperature sensing part is attached to the branch portion.

6. A semiconductor device comprising:

a semiconductor element having a gate and controlled with a gate voltage;

a gate drive circuit which controls the gate voltage;

an electrode connected to the semiconductor element, a principal current in the semiconductor element flowing through the electrode;

a temperature sensing part, in direct contact with the electrode, which senses the temperature of the electrode; and

a control section which changes, on the basis of the temperature sensed by the temperature sensing part, the content of a control signal transmitted from the outside for control of the gate voltage so that the temperature of the electrode does not exceed a predetermined temperature,

wherein the gate drive circuit controls the gate voltage according to the control signal changed by the control section.

7. A semiconductor device comprising:

a semiconductor element having a gate and controlled with a gate voltage;

a gate drive circuit which controls the gate voltage;

an electrode connected to the semiconductor element, a principal current in the semiconductor element flowing through the electrode;

a temperature sensing part which senses the temperature of the electrode;

a generation section which generates, on the basis of the temperature sensed by the temperature sensing part, a first control signal for giving a maximum amount of energization to the semiconductor element in such a

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range that the temperature of the electrode does not exceed a predetermined temperature;
 a resin which covers the semiconductor element and the electrode so that a portion of the electrode is exposed out of the resin;
 a metal part connected to the electrode in the resin and having its portion exposed out of the resin;
 a socket having as a point of contact the portion of the metal part exposed out of the resin; and
 a comparison section which compares the first control signal and a second control signal transmitted from the outside for the purpose of controlling the gate voltage, and selects a selective control signal which is one of the control signals with which the temperature of the electrode can be limited,
 wherein the gate drive circuit controls the gate voltage according to the selective control signal, and the temperature sensing part has such a shape as to be capable of being inserted in the socket.

8. An automobile comprising:
 a semiconductor device having a semiconductor element having a gate and controlled with a gate voltage, a gate

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drive circuit which controls the gate voltage, an electrode connected to the semiconductor element, a principal current in the semiconductor element flowing through the electrode, a temperature sensing part, in direct contact with the electrode, which senses the temperature of the electrode, a generation section which generates, on the basis of the temperature sensed by the temperature sensing part, a first control signal for giving a maximum amount of energization to the semiconductor element in such a range that the temperature of the electrode does not exceed a predetermined temperature, and a comparison section which compares the first control signal and a second control signal transmitted from the outside for the purpose of controlling the gate voltage, and selects a selective control signal which is one of the control signals with which the temperature of the electrode can be limited, wherein the gate drive circuit controls the gate voltage according to the selective control signal.

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